Morphotectonic Analysis of Bringi River Basin, Southeast Kashmir Valley, Northwest Himalaya, India.

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Abstract
Morphotectonic investigation using geomorphic indices serves as a tool for identification of geomorphic features in regions of active tectonic deformation. Landforms in active deformation areas are produced from the interaction of tectonic and surficial processes. One of the most significant landforms on ground is rivers , they respond to tectonic movements mainly due to uplift and tilting. Accordingly investigation of the rivers and interrelated drainage networks using geomorphic indices will enable us to get valuable information about tectonic record of the study area. In this study, tectonic activities have been surveyed in Bringi river basin by utilising geomorphic indices and field observations. In order to determine tectonic movement of Bringi river basin, five different geomorphic indices including mountain front sinuosity (Smf), valley floor width to height ratio (Vf), stream length gradient index (Sl), hypsometric curve and integral (HI), transverse topography symmetry (T) are being applied to study area. According to generated results, lower values of Smf close to 1.0 correspond to the most active mountain fronts of the study area. Vf values ranging between 0.19 - 0.50 in the area suggest deep incised and narrow V-shaped valleys with active uplift. The high values of HI and convex shape of hypsometric curve specify deep incision, high elevation and rugged relief. The values of T indicate the river has shifted to the right side of the basin.
Keywords: Morphotectonic, geomorphic indices, Bringi river basin, mountain front sinuosity, hypsometric

Introduction

The quantitative measurements of landforms are accomplished on the basis of calculation of geomorphic indices. Geomorphological studies of areas of active tectonics in the late Pleistocene and Holocene are important to evaluate earthquake hazard in tectonically active areas including Himalayas (Keller and Pinter 2002). Spatial tools such as geographical information system (GIS), DEM analysis, and topographic maps may provide useful information on this subject. Geomorphic indices applicable to fluvial systems in different regions and of varying size correlate with independently derived uplift rates (Kirby and Whipple 2001) and are applicable to a variety of tectonic settings where topography is changing (Bull and McFadden, 1977; Azor *et al.*, 2002). A combination of geomorphic and morphometric analyses of landforms and topographic analyses are utilized to obtain active tectonics (Della Seta *et al.*, 2008). Morphotectonic indices not only provide valuable information about tectonic history of an area but also correlate landforms after obtaining the necessary information from topographic maps, aerial photographs, satellite data and field data (Keller, 1986). GIS and Global mapper plays an important role for calculation of morphotectonic indices and is time saving and cost effective exercise. Several workers have used remote sensing technique for evaluation of active tectonic signatures (Cuong and Zuchiewicz 2001; Raj *et al.*, 2003; Verrios *et al.*, 2004; Jain and Verma, 2006; Bali *et al.*, 2016). Thus, considering the significance and diversity of the geomorphic indices (Bull and McFadden 1977; Keller and Pinter 1996; Wells *et al.*, 1988; Burbank and Anderson 2001; Keller and Pinter 2002), we analyzed five different geomorphic indices such as mountain front sinuosity (smf), valley floor width (Vf), hypsometric integral (Hi), hypsometric curve, stream gradient index (SL) and topographic asymmetry (T). This kind of methodology has been found to be useful in various tectonically active areas such as SW USA (Rockwell *et al.*, 1985), Pacific Costa Rica (Wells *et al.*, 1988), Mediterranean coast of Spain (Silva *et al.*, 2003; Perez-Pena 2010) and SW Kashmir Valley (Ahmad and Bhat 2012; Ahmad *et al.*, 2013.

Located in the zone of collision between the Indian and Eurasian plates, and having emerged out of mainly fluvio-glacial environment during Quaternary period, Kashmir Valley is indeed a potential region for neotectonic studtes. Besides, being a part of one of the most seismically active belts in the Himalayas, the presence of triangular facets, entrenched linear valleys, river piracy, abrupt river deflections, linear mountain fronts are some of the key features suggesting recent tectonic activity in the Kashmir Valley. However, little attention had been paid to the region until Ahmad (2010) initiated fault study in the region subsequently followed by several workers (Ahmad and Bhat 2012; Ahmad *et al.,* 2013;Bilham *et al.*,2013; Shah 2013;) including the only successful paleoseismic trench study which records minimum of four earthquakes episodes in < 40,000 years (Madden *et al.*, 2010). However, South eastern part of the Kashmir Valley (Saribal side) is deficient of active faults. Therefore, the present study is an attempt to evaluate the active tectonic signatures in Bringi river basin using topographic maps and ASTER data together with field observations.

Study area:

The study area falls in the south east of Kashmir Valley in Anantnag district of Jammu and Kashmir State. The Bringi river basin with an area of 669 km^2 covers tehsils of Kokernag and and Anantnag and located between latitudes 33^0 36` and $33^0$ 17` N and longitudes of 75^0 26´ and 75^0 40` (**Fugure 1**).

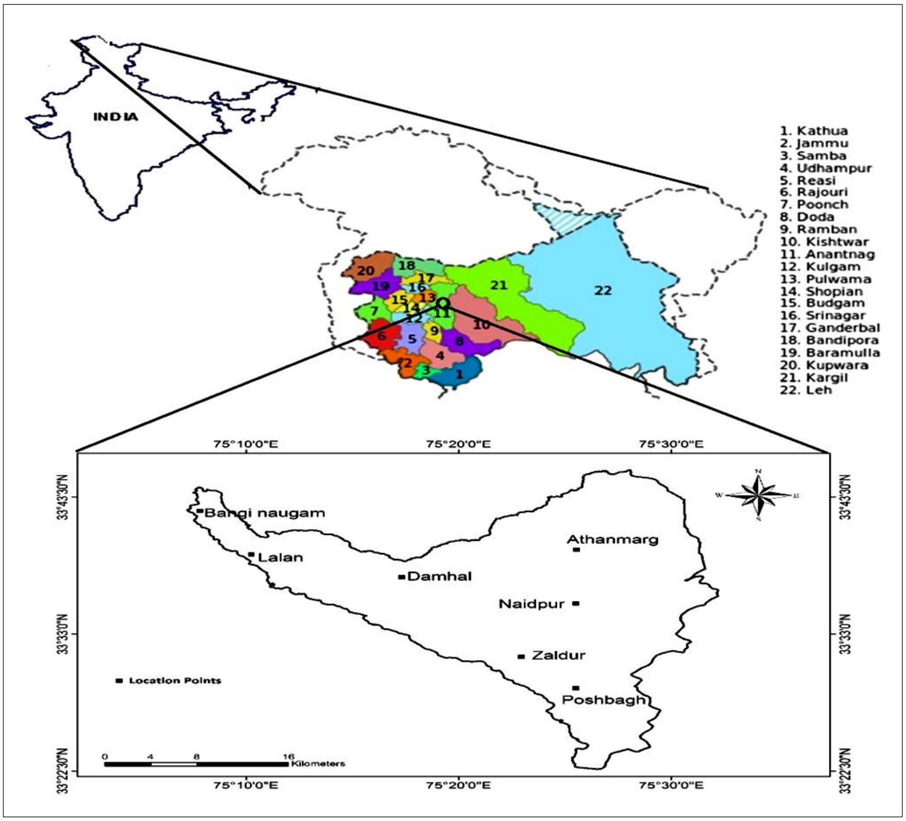

Figure 1: Study area

Geology

The Bringi river basin has a diverse rock types ranging in age from Archean to Recent. In this part of the Kashmir Valley the oldest formation comprises the Salkhala series which are found in the upper reaches of the basin and in which dynamic high grade metamorphism is evident. The Salkhala group consists of slates, phyllites and schists with interbedded crystalline limestones and flaggy quartzite. After Salkhala group Muth Quartzites and Panjal Volcanics cover the major part of the basin area. The Panjal Volcanic are of Permo-Carboniferous age and are underlain by the agglomeratic slate series, often intermixed with a thick succession of andesitic and basaltic Traps. The Panjal Volcanics are overlain by Triassic-Jurassic limestone. The rocks are of light blue colour with grey ting, compact and homogenous, sometimes mixed in composition. They are thinly bedded in the lower part of the system with frequent interstratifications of black sandy and calcareous shales, but towards the top they become monotonously uniform group of thickly bedded limestone with high coloration. The grain size ranges from fine to medium (**Figure 2**)

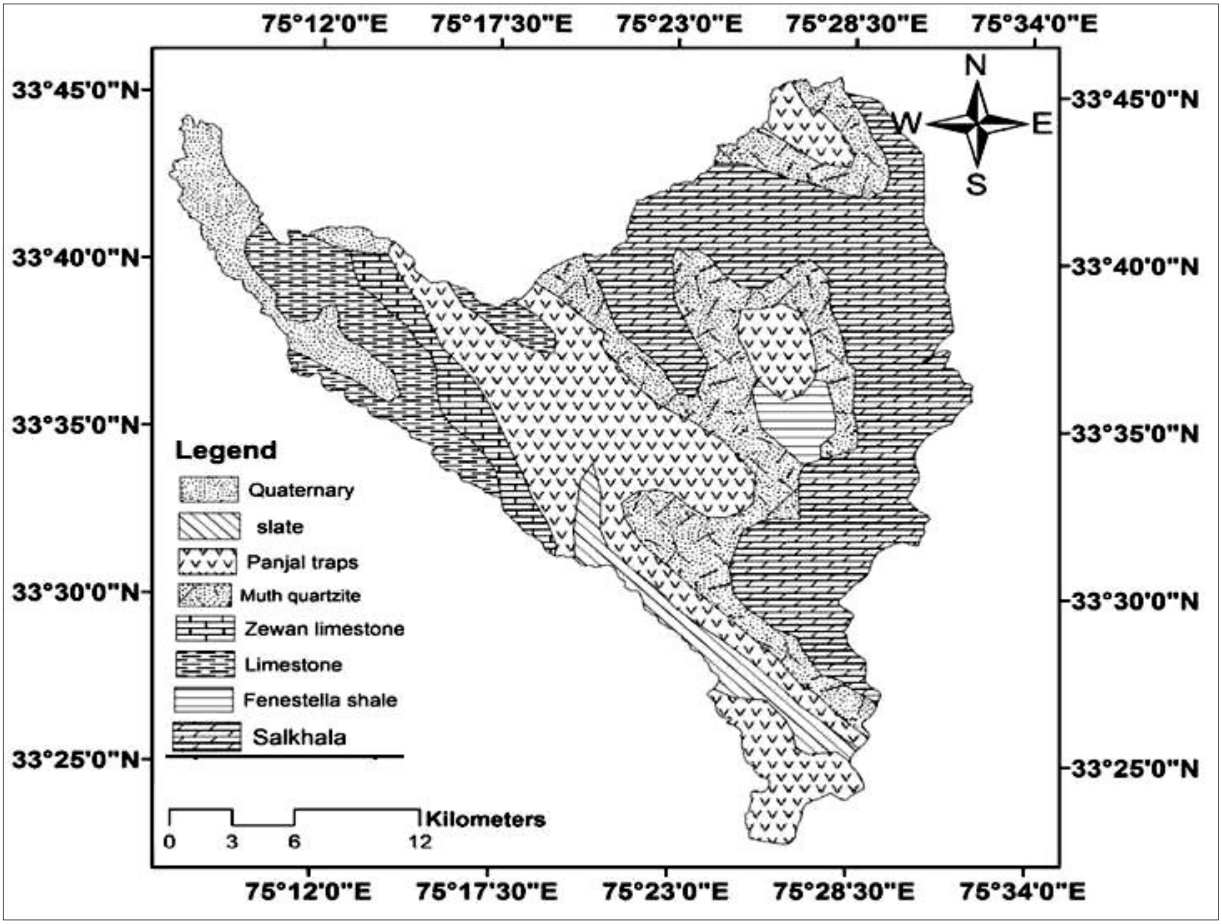

Figure 2: Geological map of the Bringi river basin.

Lower part of the study area consists of Plio-Pleistocene deposits and Recent alluvium. The Plio-Pleistocene deposits known as Karewa Formation consists of lacustrine and fluvial sediments intercalated with glacial tills.

Large amount of this Plio-Pleistocene material is brought down by water and deposited in lower parts of the basin area. Lithologically, the alluvium consists of blue grey sand, silts and varved clays, shales and sands of various hues, textures and structures. The grain size ranges from fine, medium to coarse. The colour of the alluvium varies from dark brown, reddish to flesh red.

Drainage

The 669 Km^2 Bringi basin in the SE part of the Kashmir Valley is the one of the tributary of the Jhelum river. It joins the river Jhelum after covering longitudinal distance of 28 Km. at Anantnag. The main drainage pattern of the Bringi basin is Dendritic to Sub Trellis (**Figure 3**). The main right and left bank tributaries of the Bringi river are wor nar, razparyan nar, karbudrun nar and naganol nar,Kalar nar,ahlan nar respectively.

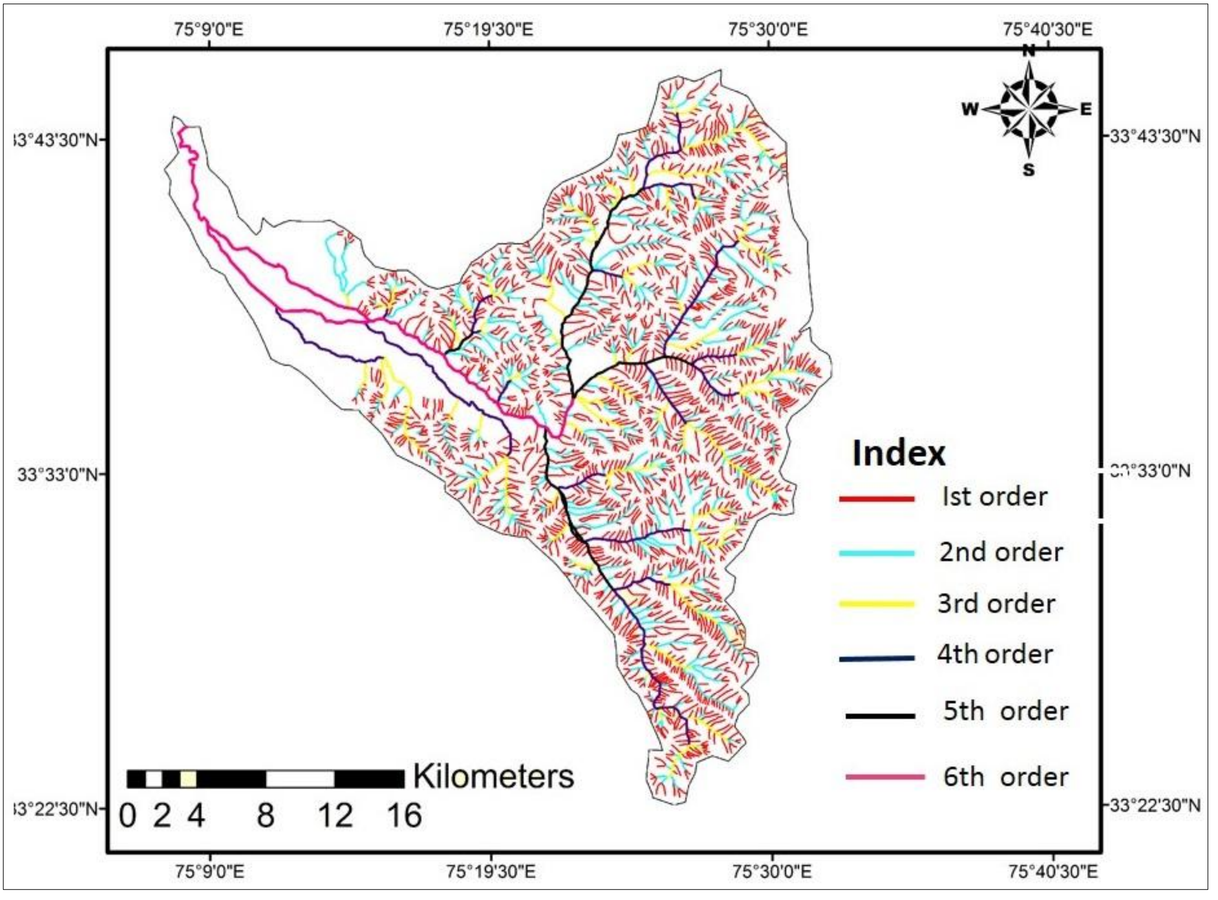

Figure 3: Drainage map of the Bringi river basin with stream order adopted after Strahler, 1957.

The river shows braided pattern at Nagum, Pethakandnar, Vailu, Larnu and Khalhar villages after Khalhar the river shows diversion of streams due to the presence of loose sediments (Karewa deposits). Above Vailu the river and its tributaries show straight course which is due to the hard rock lithology in the upper part of the basin.

Overall the drainage pattern and the geomorphology clearly indicate the structural control on the development of the Bringi river basin.

Material and Methods

In order to find out the active tectonic signatures of the Bringi basin, we first consulted Survey of India G.T. sheets (scale of 1:50,000) to delineate the area. Later, we used satellite imageries (IRS-6 Liss III of Oct 2005) and ASTER and SRTM 30 digital elevation model (DEM) together with 'Softwares' Global Mapper version (13.2) and ArcGIS (10.2) for calculation of several geomorphic indices, as these allow identification of the tectonically active regions and specific sites (Keller 1986). After the recognition of sites, field investigations were carried out to validate the results of geomorphic indices with the geomorphology, erosion, uplift, drainage and geology of the area.

Results and discussion

Mountain front sinuosity (Smf)

The geomorphology of mountain fronts reveals vital information regarding the current and past tectonic activity occurring along them. Mountain fronts are defined as major fault-bounded topographic escarpments with measurable relief exceeding the contour interval of 20 m (Wells *et al.*, 1988). The degree of erosional modification of tectonic structures and landform development is measured by the mountain front sinuosity index (Smf) (Bull, 1977; Bull and McFadden, 1977; Keller and Pinter, 2002; Rockwell *et al.*,, 1985). The index (Smf) is defined as the ratio between (Lmf) the length of the mountain front along its base at the distinct break in slope and (Ls) the straight line length of the whole mountain front (Fig. 3). The index is based on the premise that tectonically active mountain fronts are often more straight than mountain fronts in regions where erosion dominates tectonics. It is obtained by using the equation:

$$Smf = Lmf / Ls$$

Where Smf = mountain front sinuosity index, Lmf = straight line distance along a contour line, Ls = true distance along the same contour line. Most active mountain fronts have Smf values ranging between 1.0 and 1.6, whereas less active and inactive mountain fronts have Smf values ranging between 1.4 – 3.0 and >3.0, respectively (Bull and McFadden, 1977). In the study area, the mountain front sinuosity was measured in eight segments and the results are given in **Table 1**. From the observed data we conclude that the study area has active mountain fronts which illustrate that tectonic forces dominate over erosion (**Figure 4**)

Table 1: Calculated Smf values.

Segment	Lmf (m)	Ls (m)	Smf (m)= Lmf/LS	Inference
1	1467	1204	1.21	Tectonically active
2	973	781	1.24	Tectonically active
3	692	590	1.17	Tectonically active
4	705	616	1.14	Tectonically active
5	909.63	810	1.12	Tectonically active
6	663.94	600	1.1	Tectonically active
7	892	846	1.0	Tectonically active
8	785	604	1.3	Tectonically active

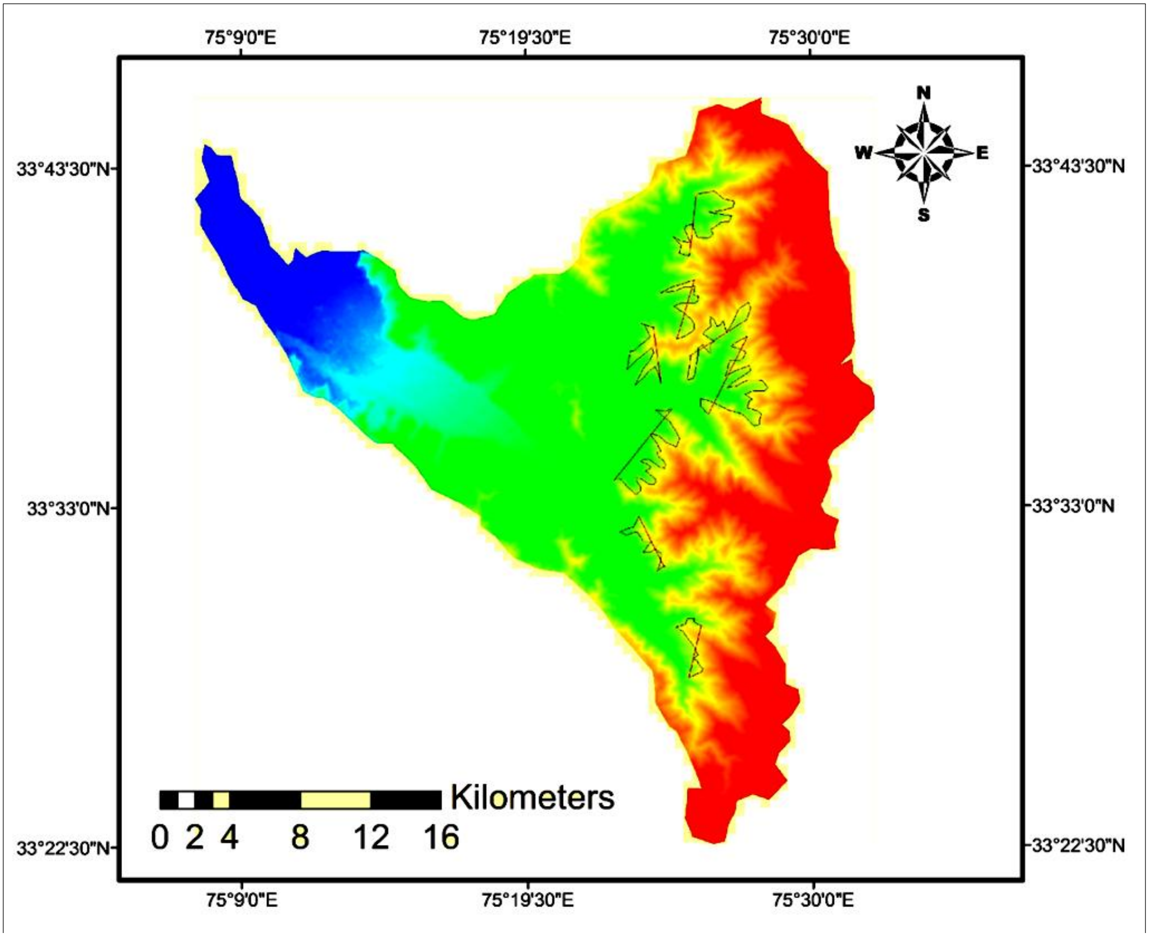

Figure 4: Mountain fronts of Bringi river basin.

Hypsometric Integral (Hi) and Hypsometric curve

Area elevation analysis or hypsometry is a powerful tool for differentiating tectonically active regions from inactive ones. The hypsometric integral (HI) is a quantitative measure of the degree of dissection of a drainage basin (Strahler, 1952). Its values are important elements in the analysis of landscape. Hypsometric integral (Strahler, 1952) can be easily obtained from topographic maps or by using Digital Elevation Models (DEM) (Pike and Wilson 1971). High values of hypsometric integral indicate that most of the topography is higher relative to the mean, such as smooth upland surface cut by deeply incised valleys. Intermediate to low value of the integral, reflect exposure of the terrain to extended erosion and are associated with more evenly dissected drainage basins. The hypsometric integral for the drainage basin is calculated as:

$$HI=Hmean-HMin/HMax-HMin$$

Where Hmean, Hmax and Hmin are the average, Maximum and minimum elevations of the basin respectively

The calculated hypsometric integral value for the study area is 0.46 indicating that the area is in mature stage with high topography and incised streams suggesting that the area is tectonically controlled.

The hypsometric curve describes the distribution of elevations across an area of land (Keller and Pinter, 1986.; Wilgoose and Hanckok.;1998). The curve is created by plotting the proportion of total basin height (relative height) against the proportion of total basin area (relative area) (**Figure 5**). The total surface area of the basin (A) is the sum of the area between each pair of adjacent contour lines. The area (a) is the surface area within the basin above a given line of elevation (h). The value of relative area (a/A) always varies from 1.0 at the lowest point in the basin (h/H=0.0) to 0.0 at the highest point in the basin (h/H=1.0) (Keller and Pinter, 1986). The combined results of hypsometric integral 0.46 and sigmoidal curve indicates that the Bringi basin is in mature stage, has high topography relative to mean and has deeply incised valleys Fig 5,6 & 7C.

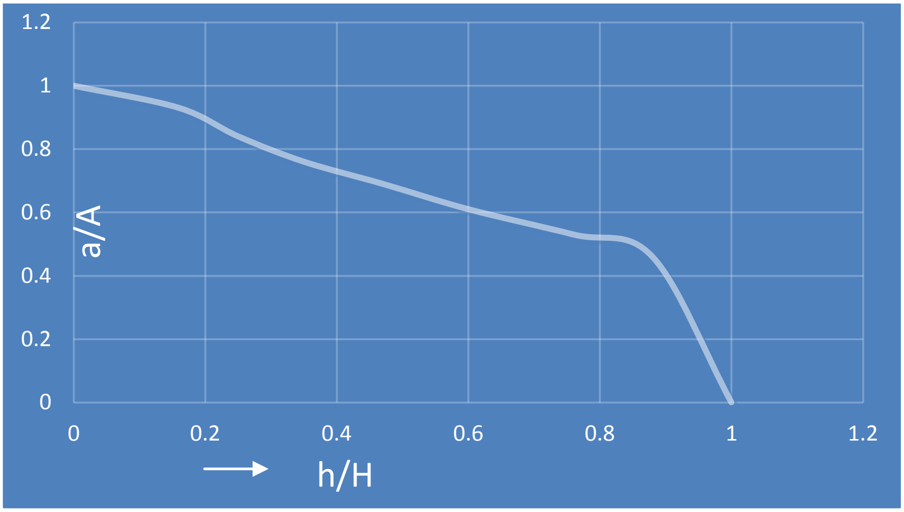

Figure 5: Hypsometric curve of Bringi river basin

Valley-floor width to valley height ratio

The ratio of valley floor width to valley height (Vf) may be expressed as:

$$Vf = 2Vfw/ [(Eld-Esc) + (Erd-Esc)]$$

Where Vf is the valley-floor width to height ratio, Vfw is the width of valley floor, Eld and Erd are elevations of the left and right valley divides respectively, and Esc is the elevation of valley floor. This index differentiates between broad-floored canyons, with relatively high values of Vf and V-shaped valleys with relatively low values. Vf values <1.0 can be classified as V-shaped valleys with streams that are actively incising, commonly associated with uplift and Vf values between 1.0 and 1.5 indicate moderately active tectonics and Vf values >1.5 are classified as U-shaped valleys subjected to major lateral erosion (Bull &Mc Fadden,1977; Ramirez and Herra,1998; Silva et al, 2003; Bull, 2007, Bali et al, 2016). The Vf values for the Bringi basin have been calculated for six section lines namely AA', BB', CC', DD', EE', FF' (**Figure 6**). The calculated values are 0.193, 0.501, 0.120, 0.290, 0.279, and 0.207 respectively. The calculated values and shape of the profiles (**Figure 7**) show that majority of the basin is V-shaped, deeply incised, associated with uplift, which in turn reflects that the basin is tectonically active. The field investigations [i e., unpaired river terraces at higher elevation and incised valleys] suggest that the basin has uplifted (**Figure 8. A-D**).

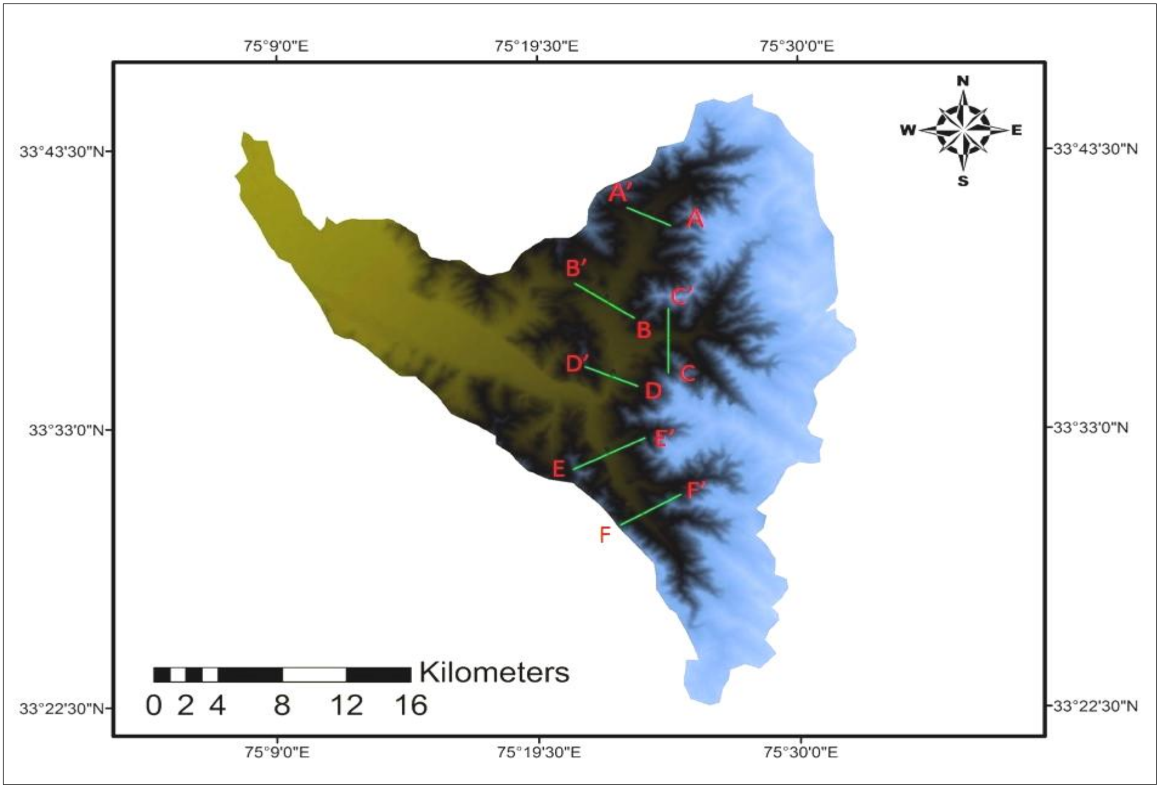

Figure 6: Section lines for the calculation of ratio of valley-floor width to valley height for Bringi basin

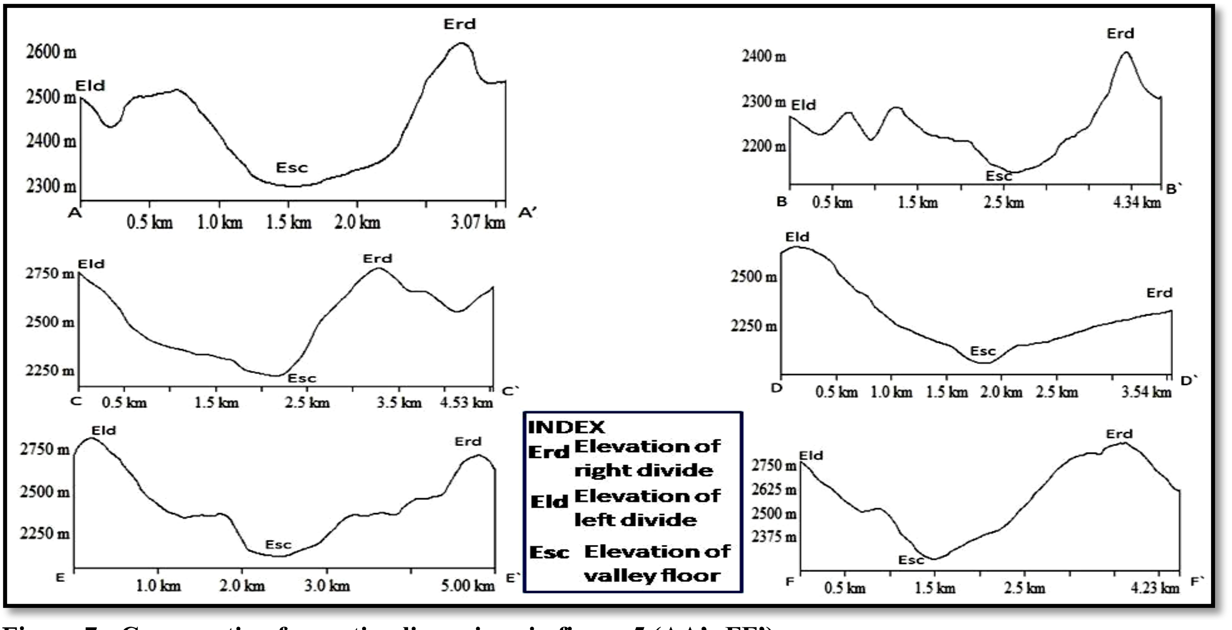

Figure 7: Cross section for section lines given in figure 5 (AA'- FF')

Figure 8: Field evidences (A) Glacial valley with dipping Panjal traps shown by black arrow (B) Unraired river terraces (C) Meandering and incised valley (D) Braiding of river bringi and shifting of river bringi Red arrows indicating the flow direction of river Bringi.

Transverse Topographic Symmetry Factor

This is another quantitative index to evaluate basin asymmetry (T) and is given by:

$$T = D_a / D_d$$

Where D_a is the distance from the midline of the drainage basin to the midline of the active meander belt, and D_d is the distance from the basin midline to the basin divide. For a perfectly symmetric basin, T = 0. As asymmetry increases, T increases and approaches a value of 1 (Cox, 1994). The transverse topographic symmetry factor (T) for the Bringi watershed has been calculated for fifteen locations (**Figure 9**). The calculated values 0.37, 0.24, 0.14, 0.27, 0.15, 0.11, 0.24, 0.25, 0.32, 0.13, 0.66, 0.53, 0.86, 0.16, 0.42 for locations a, b, c, d, e, f, g, h, I, j, k, l, m, n, o indicate the basin has shifted towards right side. The asymmetry of the basin is also supported by the drainage lines joining the trunk stream. The long and large tributaries joining from the left side are indicative of asymmetric character of the basin and shifting of river Bringi to the right side.

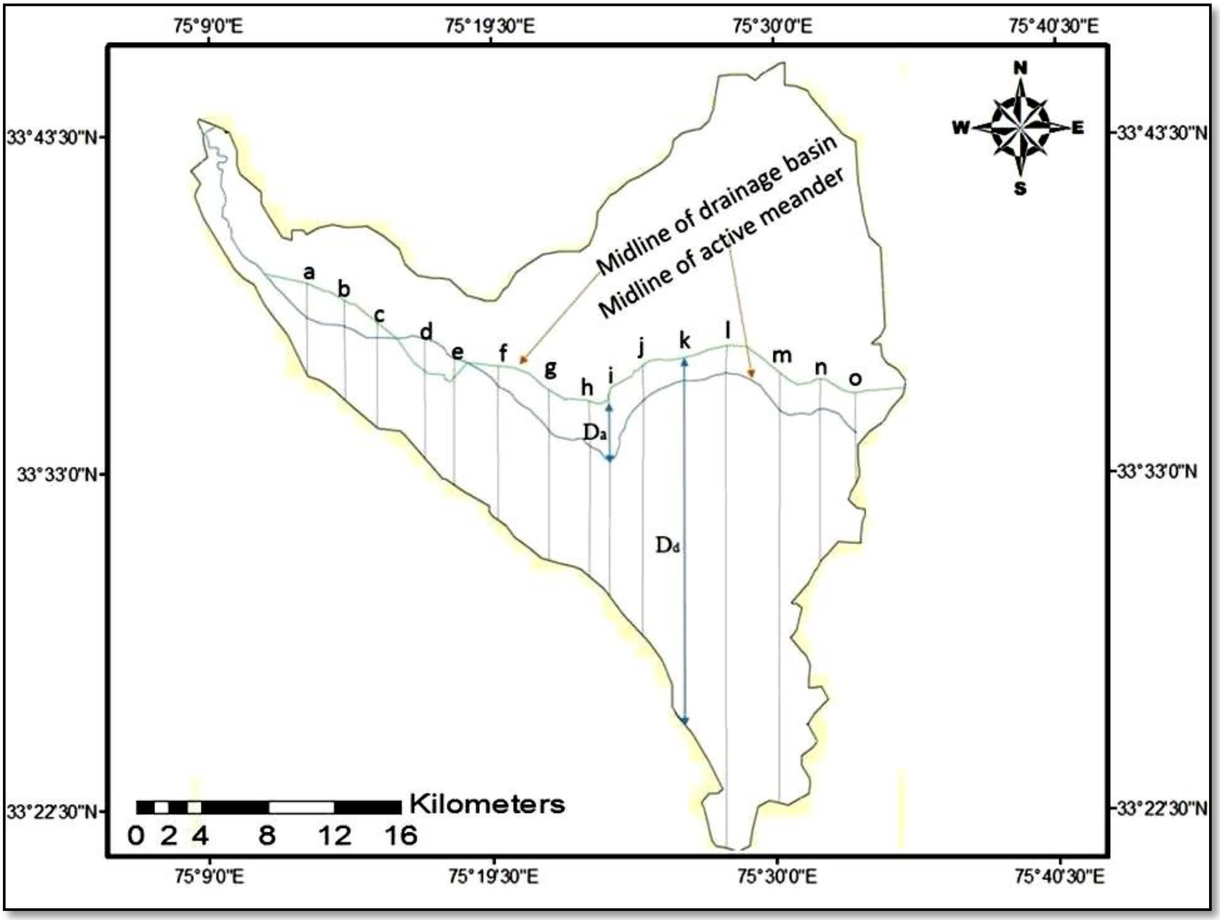

Figure 9: Sites where transverse topography symmetry is calculated

Stream gradient index(Sl)

Rivers flowing over rocks and soils of various strength/hardness tend to reach equilibrium with specific longitudinal profile and hydraulic geometries (Hack,1973; Bull,2007). Hack (1957,1973) defined the stream gradient index Sl to discuss influence of environment variables on longitudinal profile, and to test whether stream has reached equilibrium or not. For particular segment the Sl is defined as

$$Sl = \frac{\Delta H}{\Delta L} * l$$

Where ΔH the elevation difference of the segment, ΔL is the length of the segment and l is the length of the river from the midpoint of the segment to the source of the river. The Sl index can be used to evaluate recent tectonic activity (Hack, 1973; Keller and Pinter, 2002). Although an area on soft rocks with high Sl values indicates recent tectonic activity, anomalously low values of Sl may also represent such activity when rivers and streams flow through hard rocks or strike slip fault. The SL index value will increase as rivers and streams flow over an active uplift, and may have lesser values when they are flowing parallel to features such as valleys produced by strike-slip faulting (Keller and Pinter, 2002).

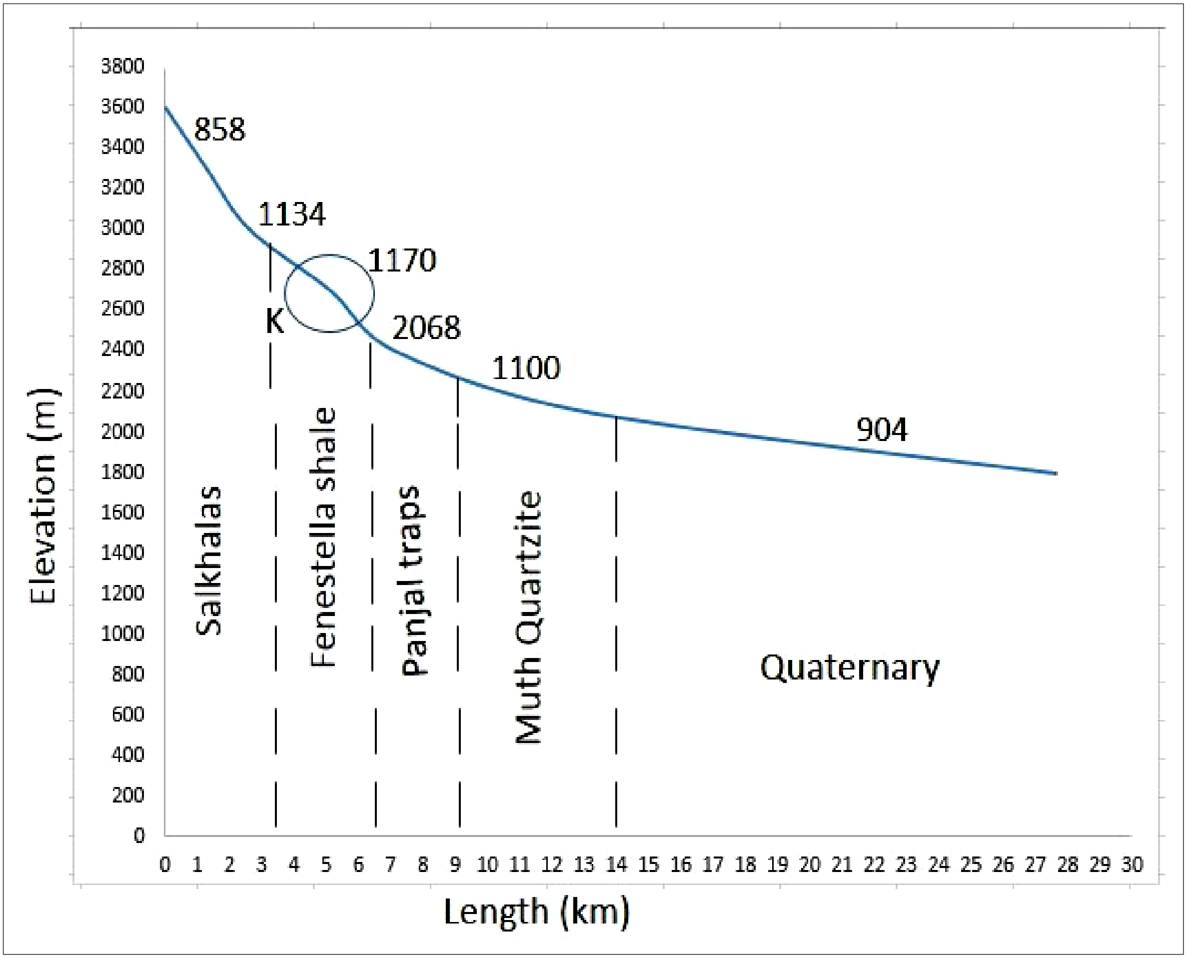

Figure 10: Longitudinal river profile of Bringi stream and plot of SL values.

The Sl has been calculated for six segments along the river. The values decrease monotonically suggesting an equilibrium between erosion and tectonic forces as is evident from the longitudinal profile (Concave up) except for the segment 3 at a distance of 5 km from the source, where a knick point has been observed (**Figure 10**).

Conclusion

The present study examined the morphotectonic analysis of the Bringi river basin (669 sq km) with emphasis on its tectonic activity based on quantification of geomorphic indices, complemented and validated by field observations. The results of the calculated morphotectonic parameters viz mountain front sinuosity (Smf), Transverse topography symmetry (T), Hypsometry integral, curve, Stream length gradient and valley floor width to height ratio(Vf) show tectonically active character of the basin. The calculated parameters T and Hypsometric index and curve reflects that watershed has tilted up to the left side and the Bringi stream has shifted to right of basin. These inferences are supported by the presence of large and long streams on the left side of the watershed. The hypsometric integral (0.46) along with sigmoidal (s-shaped) hypsometric curve indicates the mature stage of development, tectonically active and evenly dissected character of Bringi river basin. The results of Vf indicate that the basin has deeply incised valleys with actively uplifting character, also other parameters like mountain front sinuosity correlates the competing forces of erosion and tectonics. The mean value of mountain front sinuosity clearly indicates linear mountain fronts with low values signifying the tectonic forces dominates over erosion.

Overall assessment of the morphotectonic analysis reveals that the tectonic upliftment, lithology played a significant role in the landscape evolution of the Bringi river basin, and the area has experienced differential upliftment and erosion rates from time to time in the geological past.

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